Introduction

Renewable energy, far from being a new idea, was the norm for most of human history. The ability, developed in the late eighteenth century, to harness the 'fossilised' energy of coal and oil on a large scale transformed human societies. It was no accident that the explosion of the Earth's human population, from roughly 1 billion in 1800 to more than 6 billion in 2000, coincided with this energy revolution. The question people have been asking in increasing numbers for the last fifty years is, "Can it go on like this?" Most are in agreement that it can't. Whether one views climate change, population growth or resource depletion as the greatest threat to human survival, the basic problem is the same: there are limits to what our planet can provide or absorb. The renaissance of renewables is inevitable because sooner or later the oil, gas and coal will run out; because by releasing in decades the carbon absorbed over millennia we are choking the planet; and, lastly, because of economics – whereas fossil fuels are likely to become more expensive over time, renewables can only get cheaper.

This book covers most of the issues related to renewable and sustainable energy – from the purely technical to the historical, political, social and economic. It begins with a broad introduction to energy, both as a concept and a practicality, outlining the history of human energy use, profiling our current consumption, and assessing likely prospects for the future. In doing so, it uncovers and unpacks the various factors that influence our energy choices.

This book is also about the transition we must make, and indeed have already begun to make. It explains the different factors influencing that transition and the likely sacrifices that will be required. Stephen lives in Germany, so we are familiar with the debates that led to the adoption of the 'Energiewende' (literally, energy transition) in 2011 in the aftermath of the Fukushima nuclear accident in Japan.

This created a critical mass of support among the German public for a departure from nuclear energy. At that time Germany had only seventeen nuclear power plants in operation, supplying about 18 per cent of the nation's electricity. As these are phased out, they are mostly being replaced in the short term by brown coal (of which Germany has plenty) and Russian natural gas, which at the time of writing entails a precarious dependency. Renewables supply about 23 per cent of Germany's electricity and about 14 per cent of its overall energy consumption.[1] These figures may impress when compared with those of most other countries, but on their own they show that the 'energy transition' is still in its infancy.

The transition to sustainable energy will not only transform the way energy is generated but also the way it is traded. Already, the model of electricity supply devised by Thomas Edison in the early twentieth century – a relatively small number of very large power stations that supply power via a ubiquitous grid – is starting to appear outdated. Whereas a generation ago, many energy utilities prospered by operating large power plants of one particular type, many of these giant companies are now investing in a wide range of alternatives. In the United States alone, there are now close to 500,000 solar plants in operation. Most of these are small and are installed on the roofs of private homes. A quarter of them were installed in 2013 alone (Biello 2014).

Every human intervention in the natural environment has an impact. In the cases of hydropower and bioenergy, the impacts may even exceed – in terms of the environmental and social disruption – those of fossil or nuclear power. This book therefore is not biased in favour of renewables but considers the price of the 'energy transition' in terms of environmental and social impacts as well as economics.

Every movement begins with an idea, and once an idea has been widely embraced, change can follow quickly. We believe that the most immediate obstacle to a peaceful energy transition is not economic, infrastructural or political. It lies in the ability of large numbers of people to not merely reject the existing system but to imagine a new paradigm. We hope that this book can help to fill some of the gaps in your understanding of energy, and help you develop a clearer idea of how the energy transition can occur.

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[1] Source for all German energy statistics: German Association of Energy and Water Industries (Bundesverband der Energie- und Wasserwirtschaft [BDEW]) http://www.bdew.de/.

1

What Is Energy?

1.1 Aristotle in Times Square

The term 'energy' has become ubiquitous, as likely to be heard in a yoga class as at a physics lecture. In its everyday use, it has become synonymous with force, vigour, well-being and a certain kind of atmosphere. We talk about people or places having energy, a certain kind of energy, or lacking it altogether. We've become so used to using the words 'energy' and 'energetic' as pliant descriptors that we're liable to overlook their scientific significance.

A first-time visitor to Times Square, the heart of one of the world's busiest cities, is likely to first comment on the 'energy' of the place. But does this use of the term bear any relation to its scientific meaning? The Greek term ἐνέργεια (*energeia*), the origin of the English word, was probably coined by Aristotle. It combines the prefix *en*, meaning 'in' or 'at', with *ergon*, meaning 'action' or 'work'. According to Aristotle, all living beings are defined by this attribute; they are 'at work', in contrast to inactive, inanimate objects. So *energeia*, for Aristotle, was intimately connected to movement. This philosophical concept of energy remained for more than 2,000 years the main usage of the term. As late as 1737, the philosopher David Hume wrote that there were "no ideas, which occur in metaphysics, more obscure and uncertain, than those of power, force, energy or necessary connexion".

The first attempts to define energy in scientific terms date back to the seventeenth century. Isaac Newton established that the same force (gravity) which causes an apple to fall from a tree also determines the movement of the planets around the sun. Newton's contemporary Gottfried Leibniz identified something he called *vis viva* (literally 'living force'), the force of any moving thing. Leibniz began the process of quantifying energy when he concluded that while the force of a moving object depends both on its mass (weight) and its velocity (speed), velocity was far more important than mass. In other words, a light but fast-moving object has far more force than a heavy but slow-moving one. Just imagine catching a basketball, which weighs about 600 grams, thrown by a teammate. Now compare this with the impact of a 10-gram bullet fired from a gun.

The human understanding of energy took a huge leap forward during the Industrial Revolution, pioneered by industrialists who were motivated as much by commercial ambition as by scientific enquiry. For them, energy was not an abstract idea; it was the force needed to drive the machines that were rapidly replacing human and animal labour. They therefore redefined energy as the ability to perform work. This remains the most common definition to this day. But what exactly do we mean by work? An ox pulling a plough is clearly at work. The animal's 'biological' energy is converted into furrows. In scientific terms, the ox exerts a force over a distance. Since prehistoric times, humankind's work, like that of the ox, has mainly involved moving objects, whether spears, arrows, goods or the plough. By the mid-eighteenth century, it was the turn of machines, and in order to build and use those machines, people needed to understand and quantify energy.

Most work requires more than the mere application of energy. To be effective, that energy must be concentrated. We see this when we open a bottle of beer or a soft drink. It would take a very strong (and thick-skinned) person to tear the cap from the bottle without using a tool. However, even a young child can perform the same task with a bottle opener. This is because the opener works as a lever, concentrating the energy at the point where it is needed to remove the cap. When energy is concentrated not in terms of space (such as at the rim of a bottle) but in terms of time, the concept of power comes into play. Most people have gone through the ordeal of moving house at least once. If we do the move ourselves, the time required will depend largely on the muscle power we can muster from obliging friends and family members. If you have a few bodybuilders in the family, the move will be quick. If you are relying mainly on your kids, you should hire the van for the entire week. This, essentially, is the difference between energy and power: power is the *rate* at which energy is generated and consumed to perform work.

James Watt (1736–1819) was particularly interested in power. He spent most of his life improving the steam engine, which works by heating water to form steam. The vapour occupies a greater volume than liquid water does and so pushes upwards, raising a piston, just as water boiling in a pot raises the lid. Thus, Watt (and others before him) succeeded in converting the energy of heat into the energy of movement, which can be harnessed to perform a wide variety of tasks, from pumping water to turning a wheel. To convince his customers of his machine's efficacy, Watt came up with the term 'horsepower', which explains its power output relative to the main energy source of his day, the draft horse. This term, which is still used to rate certain types of engines, was later, fittingly, replaced by the *watt* as the international unit of power.

Converting Energy

Watt's horsepower measured the output of his machines, but it fell to another entrepreneur-engineer to measure the transformation of one form of energy to another. While exploring ways to improve his brewery, James Joule (1818–1889) made a breakthrough. He had been thinking of changing over from the steam engine to the newly developed electric motor. Before doing so, he wanted to compare the amount of work that could be performed by each machine. Joule constructed a device resembling an egg beater immersed in a jar of water, and he used a weight and pulley to turn the blades of the 'beater' (see Figure 1.1). The movement of the water molecules created heat, which Joule was able to measure using a thermometer. The greater the weight (force) he used, the faster the beater turned, and the greater the rise in temperature. In this way, he discovered a simple yet remarkably accurate way of measuring the relationship between work and heat.

Joule's experiment led to the formulation of one of the most important principles of physics: the first law of thermodynamics. This states that energy can be neither created nor destroyed, but merely changed from one form to another. Think of what happens when a car brakes: the energy of its movement is not lost, just converted into another form of energy. The brake pads, discs and surrounding air are warmer than they were before the driver braked. This principle is crucial to understanding how energy can be generated and used.

The Enigma of Energy

By the twentieth century, scientists had learned to quantify and measure energy, yet there remained something inherently mysterious

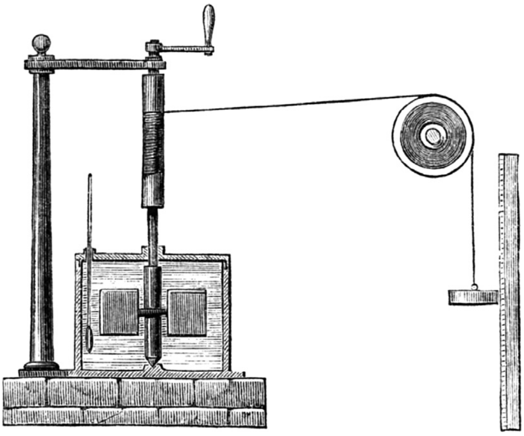

Figure 1.1. Joule's apparatus for measuring the relationship between work and heat. The fall of the weight causes the blades to turn, stirring – and thus heating – the water inside the container (calorimeter). A thermometer measures the rising temperature.

about the concept. Richard Feynman, one of the towering figures of modern physics, went as far as to admit that "in physics today, we have no knowledge of what energy is" (1970).

Energy, as we currently understand it, is force, work and power. It is at the heart of what it means to be alive: the ability to manipulate our environment to meet our needs. Thus, Aristotle's definition of energy remains essentially valid today. If the father of Western philosophy were to have stepped into a time machine that touched down on Times Square, he would recognise around him the principle of energy in action, through two factors: motion and work.

1.2 Energy: What Gets Lost in 'Translation'

Robert Frost memorably defined poetry as "what gets lost in translation." Just as meaning is inevitably lost as ideas are converted from one language to another, there is no way to convert energy without loss. Energy efficiency, like translation, is merely about minimizing that loss.

As a teacher, I always require that my students work in groups, where each person's grade is influenced by that of the whole group. It often happens that a student complains about a group-mate, typically that he or she is not pulling their weight and therefore jeopardising the performance of the group. This reflects the second principle of thermodynamics. The second principle states that an enclosed system naturally tends towards maximum disorder, or entropy. Mountains are gradually worn down by wind and water, houses need to be regularly repaired and maintained, and teenage students have a gift for creating mayhem. Being a good student means applying a great deal of order to one's behaviour. Yet this is an energy-consuming process. Sometimes my students opt for a strategy that involves a much lower energy investment; instead of studying and supporting each other, they try to sow doubt in my mind and blame each other, thus creating disorder in the classroom.

Students are not the only ones affected by entropy. All living beings expend an enormous amount of energy every day of their lives just maintaining the status quo. Order is needed to survive and triumph, at least for a while, over the many external forces that are out to get us. To live we must actively counteract the second principle, and this requires that we expend energy. The second principle implies not only that it is far easier to destroy (creating disorder) than to build (creating order) but also that any conversion will inevitably entail some dissipation of energy, usually in the form of heat. Strictly speaking, the energy converted into heat has not been lost. However, it is not easily recovered. Staring into an open wood fire on a cold winter's evening, it is easy to become mesmerised by the sparks rising with the smoke. What we are witnessing is the chemical energy stored in the wood being converted into heat and light. However, the second principle prevents the opposite occurring: heat and smoke cannot be converted back into a woodpile. Part of the energy has been so widely dispersed that it cannot be retrieved.

The Low Efficiency of Energetic Conversions

Strictly speaking, the terms 'energy production' and 'energy loss' are incorrect, as – according to the first law of thermodynamics – energy can be neither created nor destroyed. What we observe in physics or chemistry is merely a conversion from one form of energy into another. Fully efficient energy conversion is possible only in theory, and indeed most conversions are highly inefficient. The engine of a car provides a good example of how energy gets 'lost' in conversion. Cars run thanks to a controlled explosion in the combustion chamber. Thus, chemical energy (fuel) is first converted into thermal energy (heat), and then into kinetic energy (motion). However, within

Table 1.1. *Comparison of different forms of energy conversion and their efficiencies*

Process/technology	Conversion	Efficiency	Energy loss
Photosynthesis (wild plants)	light → chemical bonds	0.2–0.3%	heat
Photosynthesis (crops)	light → chemical bonds	2–5%	heat
Muscles	chemical → movement	30%	heat
Candle	chemical → light	0.01%	heat
Candle	chemical → heat	99.99%	light
Incandescent light bulb	electric → light	10%	heat
LED lamp	electric → light	50%	heat
Steam engine	chemical → heat → movement	5%	heat, noise
Electric engine	electric → movement	80%	heat, noise
Car (internal combustion engine)	chemical → heat → movement	10%	heat, noise
Gas turbine	chemical → heat	> 95%	noise
Gas turbine	chemical → heat → mechanical	60%	heat, noise

this threefold conversion process only 10 per cent of the chemical energy contained in the petrol or diesel is converted into motion. So, what happens to the other 90 per cent? About three-quarters of it is lost either as heat or consumed by the car's cooling system, while the remainder is lost as a result of friction (of tyres gears and air drag), idling, and auxiliary functions such as air-conditioning and power steering. Some conversions are even more inefficient (for example, a candle transforms no more than 0.01 per cent of the chemical energy in the wax into light), while others are considerably more efficient: an electric motor transforms about 80 per cent of the electricity consumed into mechanical energy.

1.3 The Various Forms of Energy

Consider for a moment what it takes to read these lines. First, there is the energy required to maintain a constant body temperature, then that used by the movement of the eye, and finally the energy required by the brain to process the message. At no moment in our lives do we cease to expend energy. Even during sleep the human body performs a variety of tasks: the heart beats; blood circulates; enzymes and hormones digest, protect, repair, and maintain temperature; and the brain, our most energy-intensive organ, works to maintain control of the body. Like the human body, the world partakes in a constant exchange of energy. It is, in the words of energy expert Vaclav Smil, "the only universal currency. One of its many forms must be transformed into another in order for stars to shine, planets to rotate, living things to grow, and civilizations to evolve" (Smil 2000).

Gravity is perhaps the first type of energy we experience in life. As a baby emerges from her mother's womb, she experiences for the first time a sense of weightedness. This force – no doubt disconcerting to a newborn – is truly universal. All bodies in the universe, from atoms to stars, exert a gravitational attraction on one another. This force is directly proportional to the mass of the attracting body and indirectly proportional to the distance from it. That is why astronauts can bounce around on the moon like slow-motion trampolinists (our satellite has one-fourth the mass of our planet) and why we are drawn to the Earth rather than the sun (the sun's mass is more than 300,000 times that of the Earth, but it is 150 million kilometres away).

A falling object, attracted by gravity, exerts another form of energy: kinetic energy. This can be transferred from one moving object to another, as when a tennis racket strikes a ball. However, not all the energy is converted in this way. Because the atoms within the tennis ball are excited and vibrate, they generate heat, or thermal energy. Heat is therefore a form of kinetic energy, generated at the atomic level.

Heat can be transferred either by the physical impact of particles or in the form of electromagnetic waves. We are familiar with mechanical waves; by their nature they are tangible – whether as sound travelling through air, waves in the ocean or ripples in a pond. Yet electromagnetic waves are an equally constant and natural feature of our world, in the form of radio waves, microwaves, X-rays, and gamma rays. Light is one such electromagnetic wave. Heat also radiates, in the form of infrared rays that can be "seen" by some species of snake through special thermal receptors.

The ancient Greeks found that amber, when rubbed against animal fur, exerted an attraction on small objects. As a result of this discovery, the Greek term for amber (*elektron*) forms the root of the

English word 'electricity.' Electricity describes the presence and flow of electrons, tiny negatively charged particles that orbit the nucleus of every atom. Manifestations of electricity include lightning, static electricity and the flow of electrical current in a copper wire. Certain elements, particularly metals, easily release and receive electrons. When we flick a light switch or turn on an appliance, we take advantage of a flow of electrons jumping from atom to atom along a copper wire, a flow that began, in most cases, at the nearest power plant.

A chemical reaction occurs when one chemical element 'donates' electrons to another. The fascination and comfort many of us feel while staring into a campfire may be attributable to the fact that combustion is humankind's oldest source of external energy. A typical combustion reaction sees carbon react with oxygen, releasing carbon dioxide (CO_2), water (H_2O), and energy in the form of heat and light.

Every chemical transformation is accompanied by an increase or decrease in energy. In order to lift a book from the floor onto a table, we need to expend energy; the muscles of our arms convert some of the chemical energy we consumed as food into mechanical energy. To raise the book even higher onto a bookshelf, we must expend even more energy. The floor, the table and the bookshelf represent three energetic levels. If the book falls from the shelf, the energy we invested in it will be released in kinetic and thermal energy, as the molecules in the air and the floor are excited. Because of this, we say that the book on the bookshelf has potential energy.

There are numerous ways to store energy. For example, electric energy may be stored in a battery and kinetic energy behind a dam. The electrons in the battery and the water molecules behind the dam are 'poised' to release energy. The sum of potential and kinetic energy is known as mechanical energy. This is the energy associated with the motion or position of an object. The classic example is a swinging pendulum. The pendulum passes back and forth between kinetic and potential energy. It attains its maximum kinetic energy and zero potential energy in the vertical position, because it reaches its greatest speed and is nearest the Earth at this point. At the extreme positions of its swing, on the other hand, it will have its least kinetic and greatest potential energy. The energy never leaves the system but is constantly converted between kinetic and potential. The pendulum slows down and eventually stops only because a part of the energy is converted into heat through air drag and friction at the pivot.